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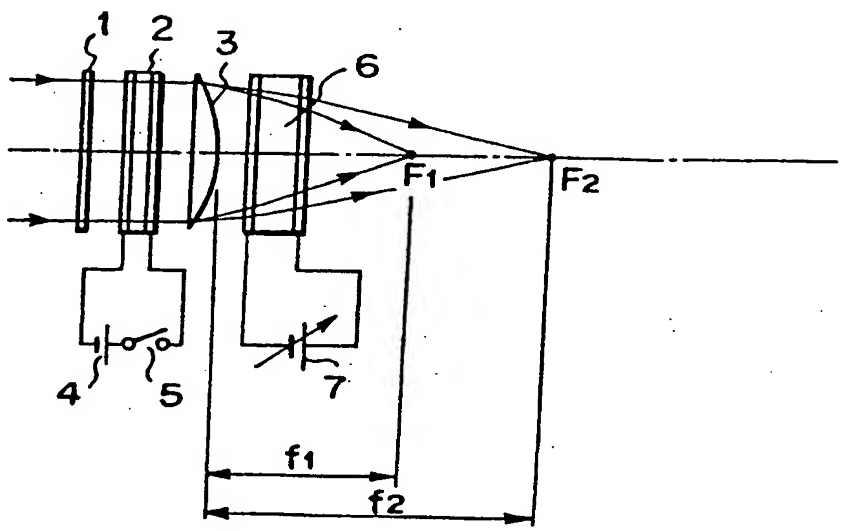
GB 1534978 JP 118618/1983 US 3663090
GB 1252276 JP 10224/1985 US 3520592
JP 157213/1982 US 4466703 US 3424513

(58) Field of search
G2F
Selected US specifications from IPC sub-class G02F

(54) Variable focal-length lens system

(57) A variable focal-length lens system comprises a first optical unit 1–5 having a switchable focal length and comprising a birefringement lens 3 (with substantially different refraction characteristics depending on the plane of polarization of an incident light beam) and a device 2 for selectively rotating the plane of polarization of the beam incident on the lens 3; and a second optical unit 6,7 forming a lens with a focal length that is continuously variable over a range equal to or larger than that of the first optical unit. The device 2 is controlled electrically, magnetically or by mechanical stress. The variable lens 6 utilises the Kerr or Pockels effect, or uses a liquid crystal, or is deformable by an actuator. Plural elements 2,3 may be employed and switched under control of a microcomputer.

FIG. 2



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1)3

FIG. 1

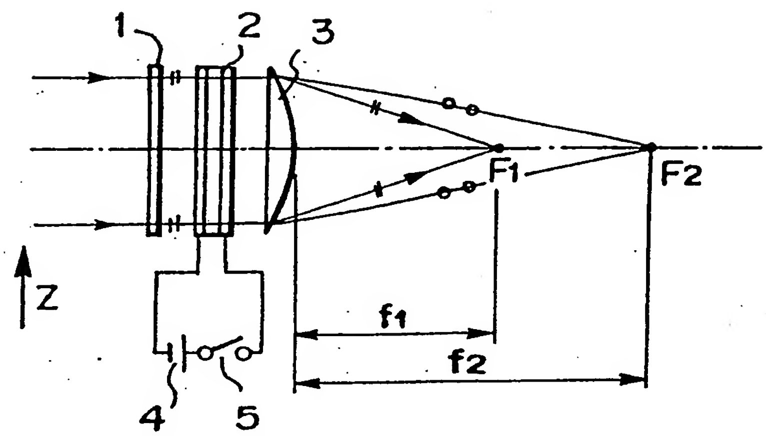


FIG. 2

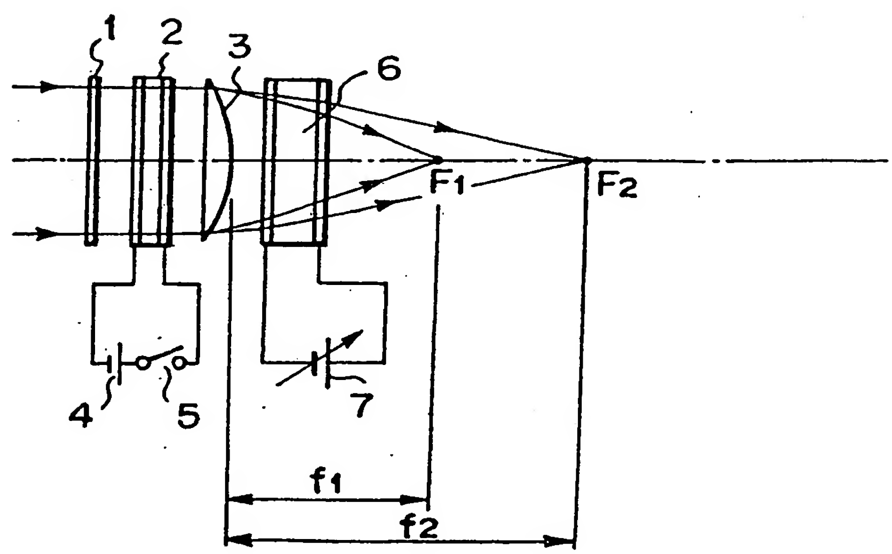


FIG. 3

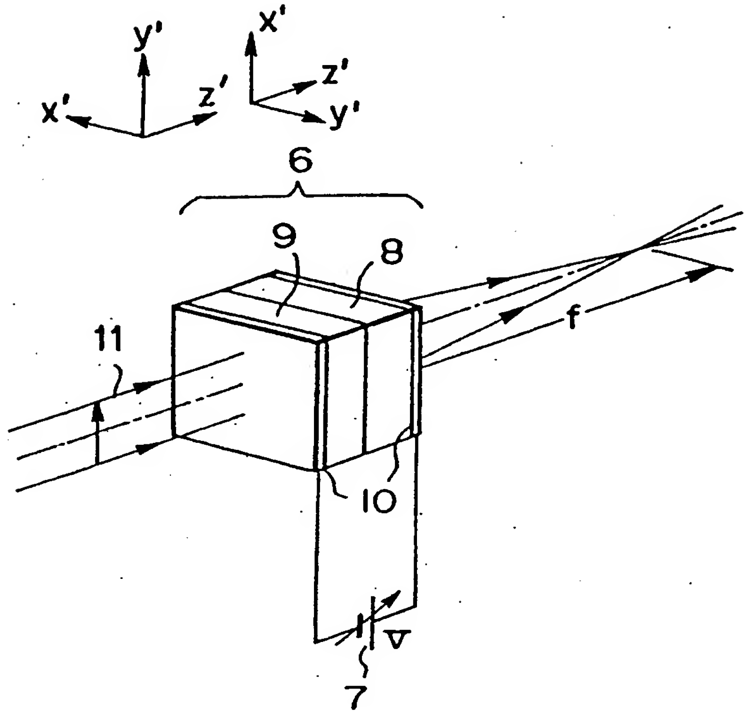


FIG. 4

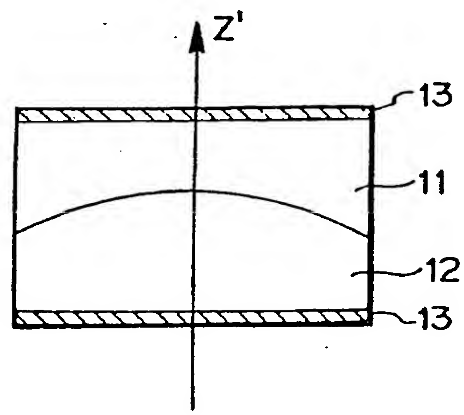
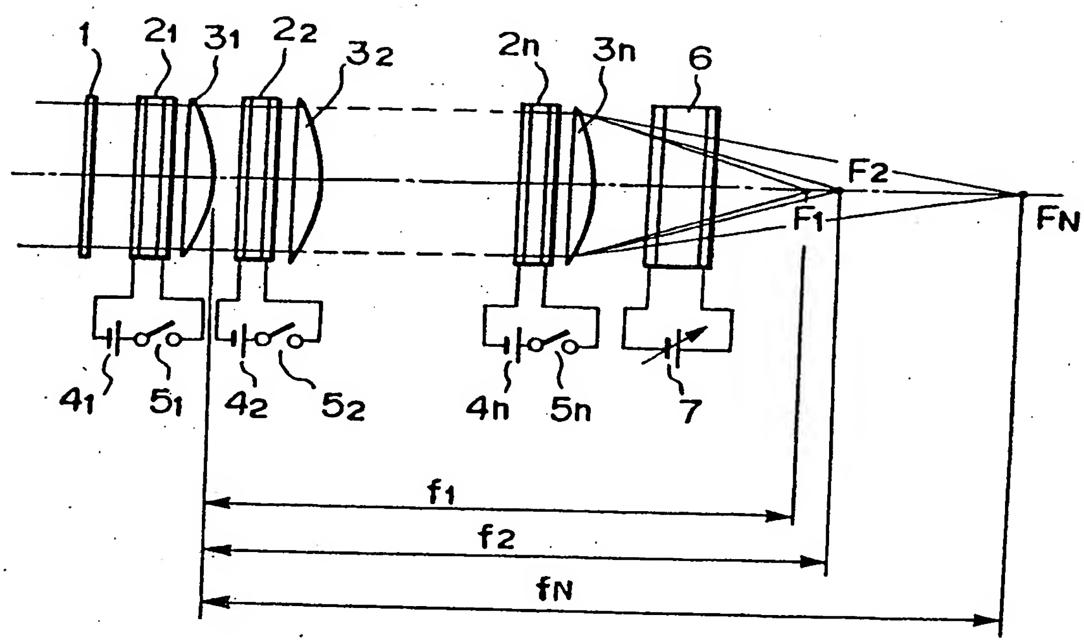


FIG. 5



SPECIFICATION

Variable focal length lens

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a variable focal length lens and, more particularly, to an improvement in a lens, a focal length of which can be changed at high speed in response to an electrical signal.

Description of the Prior Art

A focal length in a conventional variable focal length optical lens system, called a "zoom lens", is changed by moving a plurality of lens groups each constituted by a plurality of single lenses, thus changing distances between the lens groups. In such a lens system, however, a moving mechanism is required to move the lens groups. The conventional lens system does not sufficiently satisfy high-speed change in focal length, compactness and low cost requirements. Demand has arisen for a new and improved lens system which gives high performance.

Variable focal length lenses which solve the above problems and substantially eliminate moving parts are proposed by the present applicant in Japanese Patent Application Laid open Nos. 157213/1982 and 118618/1983. These lenses have lens functions upon application of an electric field to the corresponding photoelectric crystal plates, and the electric fields are changed to change the focal lengths. The focal lengths can be set at high speed. However, a conventional lens using such a photoelectric crystal requires a high electric field applied to the crystal, and the variable range of the focal length is narrow.

Japanese Patent Disclosure No. 10224/1985 and U.S.P. No. 3,520,592 describe variable focal length lenses each of which has a solid-state lens with optical anisotropy and a means for changing a polarization direction of light incident on the lens. These variable focal length lenses can provide a wide focal length range.

Fig. 1 is a schematic view showing a variable focal length lens proposed by Japanese Patent Disclosure No. 10224/1985.

Referring to Fig. 1, the variable focal length lens has a polarizing plate 1, a polarization plane rotating element 2, a birefreingent lens 3, a power source 4, and a switch 5.

The polarization plane rotating element 2 rotates a plane of polirization of light transmitted through the polarizing plate 1 upon application of an electric field. For example, the element 2 is prepared by forming transparent electrodes on two major surfaces of a Z-cut monocrystalline KH_2PO_4 plate.

The birefringent lens 3 is formed such that an optical axis (referred to as a Z-axis hereinafter) of crystal is perpendicular to the principal axis of the lens, and that the Z-axis is parallel to the surface of the drawing of Fig. 1. A refractive index of the birefringent lens 3 along a polarization direction perpendicular to the principal axis of the lens and parallel to the surface of the drawing is given as an ordinary ray refractive index n0, and a refractive index thereof along a polarization direction perpendicular to the principal axis of the lens and the surface of the drawing is given as an extraordinary ray refractive index ne.

Referring to Fig. 1, light linearly polarized by the polarizing plate 1 is incident on the birefringent lens 3 without changing the polarization direction when the switch 5 is open. The light passing through the birefringent lens 3 is refracted at the refractive index n0, and thus has a focal length f1. In this case, the transmitted light has the same polarization direction as that of the incident light, i.e., a direction parallel to the surface of the drawing. However, when the switch 5 is closed, the light is circularly polarized by the polarization plane rotating element 2 through 90°, i.e., in a direction perpendicular to the surface of the drawing. Light passing through the birefringent lens 3 thus has a focal length f2, determined by the refractive index ne.

In the conventional variable focal length lens for changing the polarization direction, focal length setting cannot be continuous but discrete. Although such a variable focal length lens has advantages in simple structure and high-speed switching, the field of practical applications is limited. This conventional variable focal length lens as a practical device lacks versatility.

SUMMARY OF THE INVENTION

The present invention has been made in consideration of the above conventional problems, and has as its object to provide a variable focal length lens wherein the focal lengths can be continuously changed while high-speed switching is performed.

In order to achive the above object of the present invention, there is provided a variable focal length lens comprising: first optical means having at least a pair of an optical element and polarization characteristic control means, the optical element being adapted to have substantially different refraction characteristics depending on polarization characteristics of an incident light beam, said polarization characteristic control means being adapted to control the polarization characteristics of the beam incident on the optical element; and second optical means for continuously changing a focal length in a length range equal to or larger than the focal length changed by the first optical means.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a conventional variable focal length lens;

Fig. 2 is a schematic view of a variable focal length lens according to an embodiment of the present invention;

Figs. 3 and 4 are schematic views showing the variable focal length lens with a continuous variable focal length; and

Fig. 5 is a schematic view of a variable focal length lens according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 2 is a schematic diagram of a variable focal length lens according to a first embodiment of the present invention.

Elements denoted by reference numerals 1 to 5 are the same as those of the conventional lens in Fig. 1. A variable focal length lens of this embodiment is substantially the same as that of the conventional lens, except that a variable focal length lens 6 as the second optical means is added.

A refractive index of the variable focal length lens 6 is changed by an electric field applied from a variable voltage source 7, so that the focal length of the lens 6 is continuously changed. It should be noted that a change in focal length is not normally large. A material of the variable focal length lens 6 is exemplified by a crystal with a primary photoelectric effect (i.e., a Pockels effect) or a crystal with a secondary photoelectric effect (i.e., a Kerr effect). The abovementioned crystal need not be used. Optical anisotropy of a material such as a liquid crystal is utilized to change the liquid crystal molecule orientation so as to arbitrarily control the refractive index. Alternatively, an arcuated surface is formed by a deformable transparent elastic material, and the radium of curvature thereof is controlled by an actuator to obtain a continuous focal length change. In a variable focal length lens made of the above member, no great increase in focal length change can be expected due to the limitations of material properties and a control system for controlling a drive voltage or the like in the same manner as in a crystal with the above-mentioned photoelectric effect.

A detailed structure of the variable focal length lens 6 is illustrated in Figs. 3 and 4. The lens 6 has KH_2PO_4 crystal members 8 and 9 with a pockels effect and transparent electrodes 10. A polarized beam 11 is incident on the variable focal length lens 6. The crystal members 8 and 9 are bonded such that the crystal directions x' and y' are perpendicular to each other with respect to a four-times rotated inverted image axis (referred to as a Z'-axis). Fig. 4 is a sectional view of the variable focal length lens 6. A boundary surface of the crystal members 8 and 9 is symmetrical about the Z'-axis. When a voltage V is supplied from the variable voltage source 7 across the transparent electrodes 10, a difference in refractive index occurs between the crystal members 8 and 9 due to the Pockels effect. The boundary surface of the crystal members 8 and 9 is arcuated, thus obtaining a lens with a focal length f. When the voltage V from the variable voltage source 7 is continuously changed, the focal length f is continuously changed. Such a variable focal length lens is described in detail in Japanese Patent Disclosure No. 118618/1983. The variable focal length lenses based on the above-mentioned principles or a variable focal length lens described in Japanese Patent Disclosure No. 157213/1982 may be used.

The focal length of the lens in this embodiment is determined as a combination of the birefringent lens 3 and the variable focal length lens 6. Comparatively discrete focal points are controlled by the switch 5. In a range between focal points F1 and F2, the focal lengths f1 and f2 are continuously changed by adjusting the voltage of the variable voltage source 7. In this case, the focal distance change range is equal to or larger than the distance between the focal points F1 and F2.

The variable focal length lens 6 need not be located at the exist side (Fig. 2) of the birefringent lens 3 serving as the first optical means. For example, when the variable focal length lens 6 has substantially the same optical axis as that of the first optical means, the variable focal length lens 6 can be arranged at any position in even an optical system in which the optical path is changed by a mirror or the like. Including the variable focal length lens 6, the variable focal length lenses of the present invention and the respective components constituting the lenses can be arranged at desired positions in given optical systems in association with other optical elements and the apparatus ratings.

Fig. 5 is a schematic view of a variable focal length lens according to another embodiment of the present invention.

Referring to Fig. 5, the variable focal length lens has a polarizing plate 1, polarization plane rotating elements 2_1, 2_2,... 2_n, birefringent lenses 3_1, 3_2,... 3_n with different radii of curvature, power sources 4_1, 4_2,...4_n, and switches 5_1, 5_2,... 5_n.

In this embodiment, n sets of polarization plane rotating elements, power sources and switches are arranged in front of the variable focal length lens 6.

The switches 5_1, 5_2,... 5_n are selectively switched to set discrete focal points F1, F2,...FN (where $N = 2^n$). In the same manner as in the first embodiment, the variable voltage source 7 is adjusted to continuously change the focal lengths f1, f2,...fN near the corresponding focal points F1, F2,... FN numbering 2^n.

When the focal length change is set to be equal to or larger than the discrete focal length obtained by operation of the switch,

the discrete focal points can be continuously interpolated by the changes in the variable focal length lens 6. The switches 5_1, 5_2,... 5_n and the variable voltage source 7 are operated to continuously change the focal lengths between the focal points F1, F2,...Fn.

In the practical application of the above embodiment, a combination of the ON/OFF operations of the switches 5_1, 5_2,... 5_n and the variable voltage source 7 is controlled by a control system (not shown) including a microcomputer, thereby obtaining a desired focal length. In the first embodiment, a desired continuous focal length can be obtained by the same technique described above. The switches are controlled to be interlocked with each other under the control of a program loaded in a microcomputer or the like. The focal lengths can be changed in accordance with purposes of various apparatuses each with the variable focal length lens of the present invention.

The apparatuses for utilizing the focal length variable lens of the present invention are exemplified by a device as a substitute of an optical pickup actuator currently used in an optical disk or the like, a position detection apparatus for detecting a position on a surface utilizing the principle of AF (Auto Focus), and a device for changing a focusing state (focusing position) of the beam on a beam radiation surface. Furthermore, the variable focal length lens can be applied to an apparatus for changing a beam diameter for various purposes or other various apparatuses for changing a focal length of an optical system.

The present invention is not limited to the particular embodiments described above. Various changes and modifications can be made within the spirit and scope of the invention.

For example, when a light source generates a linearly polarized beam such as a laser beam, the polarizing plate can be omitted.

The polarization plane rotating element is constituted by an element for rotating the plane of polarization upon application of an electric field thereto. However, the plane rotating element can also be exemplified by an element for rotating the polarization direction by a birefringence using a mechanical load with an optical elastic effect, or an element such as a Faraday rotator, for rotating the plane of polarization by utilizing the magnetic Faraday effect.

The optical axis of the birefringent lens, its shape and an arrangement order of the birefringent lens and the variable focal length lens 6 are not limited to the embodiments described above.

According to the variable focal length lens of the present invention as described above, the focal length change range can be windened and the focal length can be continuously changed. Furthermore, the first optical means consisting of the variable focal length lens for obtaining discrete focal lengths has an infinite focal length change range in principle. By adding the second optical means for interpolating the discrete focal points to obtain a continuously changing focal length, an infinite continuous focal length change can be obtained. By utilizing both a feature of a conventional variable focal length lens which provides only discrete focal length and a feature of a variable focal length lens which provides only a continuous focal length within a narrow range, and by compensating for the drawbacks of these variable focal length lenses, an ideal variable focal length lens can be achieved. Furthermore, since the variable focal length lens can be electrically controlled, it can be switched at high speed, and its construction is simple.

CLAIMS

1. A variable focal length lens comprising:
first optical means for discretely changing a focal length, said first optical means being provided with an optical element with substantially different refraction characteristics depending on polarization characteristics of an incident light beam and polarization characteristic control means for controlling the polarization characteristics of the beam incident on said optical element; and
second optical means for continuously changing the focal length, said second optical means being adapted to change a focal length thereof in a range equal to or larger than that of said first optical means.

2. A lens according to claim 1, wherein said first optical means comprises a plurality of optical means which are controlled to be interlocked with each other.

3. A lens according to claim 1, wherein said optical element comprises a birefringent lens.

4. A lens according to claim 1, wherein said polarization characteristic control means comprises:
a photoelectric crystal having an optical axis directed ina predetermined direction with respect to an optical axis of said variable focal length lens;
a pair of electrodes formed on two opposite surfaces of said photoelectric crystal; and
means for supplying a voltage to said pair of electrodes.

5. A lens according to claim 1, wherein said polarization characteristic control means switches the incident beam between two linearly polarizing surfaces which are perpendicular to each other.

6. A lens according to claim 1, wherein said second optical means basically comprises a photoelectric crystal.

7. A variable focal length lens substantially as herein described with reference to Fig. 2 of the accompanying drawings.

8. A variable focal length lens substantially as herein described with reference to Fig. 4 of

the accompanying drawings.

9. A variable focal length lens substantially as herein described with reference to Fig. 5 of the accompanying drawings.

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